

# Midrapidity $\Lambda$ and $\bar{\Lambda}$ Production in Au + Au Collisions at $\sqrt{s_{NN}} = 130$ GeV

C. Adler,<sup>11</sup> Z. Ahammed,<sup>23</sup> C. Allgower,<sup>12</sup> J. Amonett,<sup>14</sup> B. D. Anderson,<sup>14</sup> M. Anderson,<sup>5</sup> G. S. Averichev,<sup>9</sup> J. Balewski,<sup>12</sup> O. Barannikova,<sup>9,23</sup> L. S. Barnby,<sup>14</sup> J. Baudot,<sup>13</sup> S. Bekele,<sup>20</sup> V. V. Belaga,<sup>9</sup> R. Bellwied,<sup>31</sup> J. Berger,<sup>11</sup> H. Bichsel,<sup>30</sup> A. Billmeier,<sup>31</sup> L. C. Bland,<sup>2</sup> C. O. Blyth,<sup>3</sup> B. E. Bonner,<sup>24</sup> A. Boucham,<sup>26</sup> A. Brandin,<sup>18</sup> A. Bravar,<sup>2</sup> R. V. Cadman,<sup>1</sup> H. Caines,<sup>33</sup> M. Calderón de la Barca Sánchez,<sup>2</sup> A. Cardenas,<sup>23</sup> J. Carroll,<sup>15</sup> J. Castillo,<sup>26</sup> M. Castro,<sup>31</sup> D. Cebra,<sup>5</sup> P. Chaloupka,<sup>20</sup> S. Chattopadhyay,<sup>31</sup> Y. Chen,<sup>6</sup> S. P. Chernenko,<sup>9</sup> M. Cherney,<sup>8</sup> A. Chikanian,<sup>33</sup> B. Choi,<sup>28</sup> W. Christie,<sup>2</sup> J. P. Coffin,<sup>13</sup> T. M. Cormier,<sup>31</sup> J. G. Cramer,<sup>30</sup> H. J. Crawford,<sup>4</sup> W. S. Deng,<sup>2</sup> A. A. Derevschikov,<sup>22</sup> L. Didenko,<sup>2</sup> T. Dietel,<sup>11</sup> J. E. Draper,<sup>5</sup> V. B. Dunin,<sup>9</sup> J. C. Dunlop,<sup>33</sup> V. Eckardt,<sup>16</sup> L. G. Efimov,<sup>9</sup> V. Emelianov,<sup>18</sup> J. Engelage,<sup>4</sup> G. Eppley,<sup>24</sup> B. Erasmus,<sup>26</sup> P. Fachini,<sup>2</sup> V. Faine,<sup>2</sup> J. Faivre,<sup>13</sup> K. Filimonov,<sup>15</sup> E. Finch,<sup>33</sup> Y. Fisyak,<sup>2</sup> D. Flierl,<sup>11</sup> K. J. Foley,<sup>2</sup> J. Fu,<sup>15,32</sup> C. A. Gagliardi,<sup>27</sup> N. Gagunashvili,<sup>9</sup> J. Gans,<sup>33</sup> L. Gaudichet,<sup>26</sup> M. Germain,<sup>13</sup> F. Geurts,<sup>24</sup> V. Ghazikhanian,<sup>6</sup> O. Grachov,<sup>31</sup> V. Grigoriev,<sup>18</sup> M. Guedon,<sup>13</sup> E. Gushin,<sup>18</sup> T. J. Hallman,<sup>2</sup> D. Hardtke,<sup>15</sup> J. W. Harris,<sup>33</sup> T. W. Henry,<sup>27</sup> S. Heppelmann,<sup>21</sup> T. Herston,<sup>23</sup> B. Hippolyte,<sup>13</sup> A. Hirsch,<sup>23</sup> E. Hjort,<sup>15</sup> G. W. Hoffmann,<sup>28</sup> M. Horsley,<sup>33</sup> H. Z. Huang,<sup>6</sup> T. J. Humanic,<sup>20</sup> G. Igo,<sup>6</sup> A. Ishihara,<sup>28</sup> Yu. I. Ivanshin,<sup>10</sup> P. Jacobs,<sup>15</sup> W. W. Jacobs,<sup>12</sup> M. Janik,<sup>29</sup> I. Johnson,<sup>15</sup> P. G. Jones,<sup>3</sup> E. G. Judd,<sup>4</sup> M. Kaneta,<sup>15</sup> M. Kaplan,<sup>7</sup> D. Keane,<sup>14</sup> J. Kiryluk,<sup>6</sup> A. Kisiel,<sup>29</sup> J. Klay,<sup>15</sup> S. R. Klein,<sup>15</sup> A. Klyachko,<sup>12</sup> A. S. Konstantinov,<sup>22</sup> M. Kopytine,<sup>14</sup> L. Kotchenda,<sup>18</sup> A. D. Kovalenko,<sup>9</sup> M. Kramer,<sup>19</sup> P. Kravtsov,<sup>18</sup> K. Krueger,<sup>1</sup> C. Kuhn,<sup>13</sup> A. I. Kulikov,<sup>9</sup> G. J. Kunde,<sup>33</sup> C. L. Kunz,<sup>7</sup> R. Kh. Kutuev,<sup>10</sup> A. A. Kuznetsov,<sup>9</sup> L. Lakehal-Ayat,<sup>26</sup> M. A. C. Lamont,<sup>3</sup> J. M. Landgraf,<sup>2</sup> S. Lange,<sup>11</sup> C. P. Lansdell,<sup>28</sup> B. Lasiuk,<sup>33</sup> F. Laue,<sup>2</sup> J. Lauret,<sup>2</sup> A. Lebedev,<sup>2</sup> R. Lednický,<sup>9</sup> V. M. Leontiev,<sup>22</sup> M. J. LeVine,<sup>2</sup> Q. Li,<sup>31</sup> S. J. Lindenbaum,<sup>19</sup> M. A. Lisa,<sup>20</sup> F. Liu,<sup>32</sup> L. Liu,<sup>32</sup> Z. Liu,<sup>32</sup> Q. J. Liu,<sup>30</sup> T. Ljubicic,<sup>2</sup> W. J. Llope,<sup>24</sup> G. LoCurto,<sup>16</sup> H. Long,<sup>6</sup> R. S. Longacre,<sup>2</sup> M. Lopez-Noriega,<sup>20</sup> W. A. Love,<sup>2</sup> T. Ludlam,<sup>2</sup> D. Lynn,<sup>2</sup> J. Ma,<sup>6</sup> R. Majka,<sup>33</sup> S. Margetis,<sup>14</sup> C. Markert,<sup>33</sup> L. Martin,<sup>26</sup> J. Marx,<sup>15</sup> H. S. Matis,<sup>15</sup> Yu. A. Matulenko,<sup>22</sup> T. S. McShane,<sup>8</sup> F. Meissner,<sup>15</sup> Yu. Melnick,<sup>22</sup> A. Meschanin,<sup>22</sup> M. Messer,<sup>2</sup> M. L. Miller,<sup>33</sup> Z. Milosevich,<sup>7</sup> N. G. Minaev,<sup>22</sup> J. Mitchell,<sup>24</sup> V. A. Moiseenko,<sup>10</sup> C. F. Moore,<sup>28</sup> V. Morozov,<sup>15</sup> M. M. de Moura,<sup>31</sup> M. G. Munhoz,<sup>25</sup> J. M. Nelson,<sup>3</sup> P. Nevski,<sup>2</sup> V. A. Nikitin,<sup>10</sup> L. V. Nogach,<sup>22</sup> B. Norman,<sup>14</sup> S. B. Nurushev,<sup>22</sup> G. Odyniec,<sup>15</sup> A. Ogawa,<sup>21</sup> V. Okorokov,<sup>18</sup> M. Oldenburg,<sup>16</sup> D. Olson,<sup>15</sup> G. Paic,<sup>20</sup> S. U. Pandey,<sup>31</sup> Y. Panebratsev,<sup>9</sup> S. Y. Panitkin,<sup>2</sup> A. I. Pavlinov,<sup>31</sup> T. Pawlak,<sup>29</sup> V. Perevoztchikov,<sup>2</sup> W. Peryt,<sup>29</sup> V. A. Petrov,<sup>10</sup> M. Planinic,<sup>12</sup> J. Pluta,<sup>29</sup> N. Porile,<sup>23</sup> J. Porter,<sup>2</sup> A. M. Poskanzer,<sup>15</sup> E. Potrebenikova,<sup>9</sup> D. Prindle,<sup>30</sup> C. Pruneau,<sup>31</sup> J. Putschke,<sup>16</sup> G. Rai,<sup>15</sup> G. Rakness,<sup>12</sup> O. Ravel,<sup>26</sup> R. L. Ray,<sup>28</sup> S. V. Razin,<sup>9,12</sup> D. Reichhold,<sup>8</sup> J. G. Reid,<sup>30</sup> G. Renault,<sup>26</sup> F. Retiere,<sup>15</sup> A. Ridiger,<sup>18</sup> H. G. Ritter,<sup>15</sup> J. B. Roberts,<sup>24</sup> O. V. Rogachevski,<sup>9</sup> J. L. Romero,<sup>5</sup> A. Rose,<sup>31</sup> C. Roy,<sup>26</sup> V. Rykov,<sup>31</sup> I. Sakrejda,<sup>15</sup> S. Salur,<sup>33</sup> J. Sandweiss,<sup>33</sup> A. C. Saulys,<sup>2</sup> I. Savin,<sup>10</sup> J. Schambach,<sup>28</sup> R. P. Scharenberg,<sup>23</sup> N. Schmitz,<sup>16</sup> L. S. Schroeder,<sup>15</sup> A. Schüttauf,<sup>16</sup> K. Schweda,<sup>15</sup> J. Seger,<sup>8</sup> D. Seliverstov,<sup>18</sup> P. Seyboth,<sup>16</sup> E. Shahaliev,<sup>9</sup> K. E. Shestermanov,<sup>22</sup> S. S. Shimanskii,<sup>9</sup> V. S. Shvetcov,<sup>10</sup> G. Skoro,<sup>9</sup> N. Smirnov,<sup>33</sup> R. Snellings,<sup>15</sup> P. Sorensen,<sup>6</sup> J. Sowinski,<sup>12</sup> H. M. Spinka,<sup>1</sup> B. Srivastava,<sup>23</sup> E. J. Stephenson,<sup>12</sup> R. Stock,<sup>11</sup> A. Stolpovsky,<sup>31</sup> M. Strikhanov,<sup>18</sup> B. Stringfellow,<sup>23</sup> C. Struck,<sup>11</sup> A. A. P. Suaide,<sup>31</sup> E. Sugarbaker,<sup>20</sup> C. Suire,<sup>2</sup> M. Šumbera,<sup>20</sup> B. Surrow,<sup>2</sup> T. J. M. Symons,<sup>15</sup> A. Szanto de Toledo,<sup>25</sup> P. Szarwas,<sup>29</sup> A. Tai,<sup>6</sup> J. Takahashi,<sup>25</sup> A. H. Tang,<sup>15</sup> J. H. Thomas,<sup>15</sup> M. Thompson,<sup>3</sup> V. Tikhomirov,<sup>18</sup> M. Tokarev,<sup>9</sup> M. B. Tonjes,<sup>17</sup> T. A. Trainor,<sup>30</sup> S. Trentalange,<sup>6</sup> R. E. Tribble,<sup>27</sup> V. Trofimov,<sup>18</sup> O. Tsai,<sup>6</sup> T. Ullrich,<sup>2</sup> D. G. Underwood,<sup>1</sup> G. Van Buren,<sup>2</sup> A. M. VanderMolen,<sup>17</sup> I. M. Vasilevski,<sup>10</sup> A. N. Vasiliev,<sup>22</sup> S. E. Vigdor,<sup>12</sup> S. A. Voloshin,<sup>31</sup> F. Wang,<sup>23</sup> H. Ward,<sup>28</sup> J. W. Watson,<sup>14</sup> R. Wells,<sup>20</sup> G. D. Westfall,<sup>17</sup> C. Whitten, Jr.,<sup>6</sup> H. Wieman,<sup>15</sup> R. Willson,<sup>20</sup> S. W. Wissink,<sup>12</sup> R. Witt,<sup>33</sup> J. Wood,<sup>6</sup> N. Xu,<sup>15</sup> Z. Xu,<sup>2</sup> A. E. Yakutin,<sup>22</sup> E. Yamamoto,<sup>15</sup> J. Yang,<sup>6</sup> P. Yepes,<sup>24</sup> V. I. Yurevich,<sup>9</sup> Y. V. Zanevski,<sup>9</sup> I. Zborovský,<sup>9</sup> H. Zhang,<sup>33</sup> W. M. Zhang,<sup>14</sup> R. Zoukarneev,<sup>10</sup> and A. N. Zubarev<sup>9</sup>

(STAR Collaboration)

<sup>1</sup>Argonne National Laboratory, Argonne, Illinois 60439

<sup>2</sup>Brookhaven National Laboratory, Upton, New York 11973

<sup>3</sup>University of Birmingham, Birmingham, United Kingdom

<sup>4</sup>University of California, Berkeley, California 94720

<sup>5</sup>University of California, Davis, California 95616

<sup>6</sup>University of California, Los Angeles, California 90095

<sup>7</sup>Carnegie Mellon University, Pittsburgh, Pennsylvania 15213

<sup>8</sup>Creighton University, Omaha, Nebraska 68178

<sup>9</sup>Laboratory for High Energy (JINR), Dubna, Russia

- <sup>10</sup>Particle Physics Laboratory (JINR), Dubna, Russia  
<sup>11</sup>University of Frankfurt, Frankfurt, Germany  
<sup>12</sup>Indiana University, Bloomington, Indiana 47408  
<sup>13</sup>Institut de Recherches Subatomiques, Strasbourg, France  
<sup>14</sup>Kent State University, Kent, Ohio 44242  
<sup>15</sup>Lawrence Berkeley National Laboratory, Berkeley, California 94720  
<sup>16</sup>Max-Planck-Institut fuer Physik, Munich, Germany  
<sup>17</sup>Michigan State University, East Lansing, Michigan 48824  
<sup>18</sup>Moscow Engineering Physics Institute, Moscow Russia  
<sup>19</sup>City College of New York, New York, New York 10031  
<sup>20</sup>The Ohio State University, Columbus, Ohio 43210  
<sup>21</sup>Pennsylvania State University, University Park, Pennsylvania 16802  
<sup>22</sup>Institute of High Energy Physics, Protvino, Russia  
<sup>23</sup>Purdue University, West Lafayette, Indiana 47907  
<sup>24</sup>Rice University, Houston, Texas 77251  
<sup>25</sup>Universidade de Sao Paulo, Sao Paulo, Brazil  
<sup>26</sup>SUBATECH, Nantes, France  
<sup>27</sup>Texas A & M, College Station, Texas 77843  
<sup>28</sup>University of Texas, Austin, Texas 78712  
<sup>29</sup>Warsaw University of Technology, Warsaw, Poland  
<sup>30</sup>University of Washington, Seattle, Washington 98195  
<sup>31</sup>Wayne State University, Detroit, Michigan 48201  
<sup>32</sup>Institute of Particle Physics, CCNU (HZNU), Wuhan, 430079 China  
<sup>33</sup>Yale University, New Haven, Connecticut 06520  
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We report the first measurement of strange ( $\Lambda$ ) and antistrange ( $\bar{\Lambda}$ ) baryon production from  $\sqrt{s_{NN}} = 130$  GeV Au + Au collisions at the Relativistic Heavy Ion Collider (RHIC). Rapidity density and transverse mass distributions at midrapidity are presented as a function of centrality. The yield of  $\Lambda$  and  $\bar{\Lambda}$  hyperons is found to be approximately proportional to the number of negative hadrons. The production of  $\bar{\Lambda}$  hyperons relative to negative hadrons increases very rapidly with transverse momentum. The magnitude of the increase cannot be described by existing hadronic string fragmentation models alone.

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Ultrarelativistic nucleus-nucleus collisions provide a unique means to create nuclear matter of high energy density (temperature) and/or baryon density over an extended volume [1]. The first results from the Relativistic Heavy Ion Collider (RHIC) have shown that the large charged particle multiplicity, measured in Au + Au collisions at  $\sqrt{s_{NN}} = 130$  GeV, corresponds to an energy density significantly higher than that previously achieved in heavy ion collisions [2–4]. The yield of baryons and antibaryons produced in relativistic nuclear collisions is very important because it is sensitive to two fundamental, not yet fully understood aspects of hadron production dynamics: baryon/antibaryon pair production and the transport of baryon number from beam rapidity to midrapidity. The nature of baryon/antibaryon production itself is the subject of much interest, with theoretical conjecture addressing a range of possible mechanisms from string fragmentation [5] to exotic mechanisms involving quantum chromodynamics (QCD) domain walls [6]. The physical nature of the entity which carries the baryon number and the means by which the baryon number is transported over a large rapidity gap into the midrapidity region are also subjects of considerable experimental and theoretical interest [7–9].

Strange baryon/antibaryon production is particularly interesting due to the increased sensitivity to the availability of strange/antistrange quarks, which is expected to be suppressed relative to light quarks in hadronic matter due to the strange quark mass. Strangeness production has long been predicted to be a signature of quark gluon plasma formation [10]. The strangeness production in previous generations of heavy ion experiments has been observed to be significantly increased compared to those from  $p + p$ ,  $p + A$ , and light ion collisions [11–14], although questions remain about the exact strangeness production mechanism. In particular, the relative importance of strange baryon production from hadronic rescattering differs between calculations [15,16], depending on both the evolution of the system and the scattering cross sections assumed. Exotic dynamical mechanisms that have been proposed for strange baryon production include, for example, color string ropes [17], string fusion [18], and multimesonic reactions [19]. All require a high local energy density and therefore suggest that strangeness production occurs early in the collision.

In this Letter we report on midrapidity ( $|y| < 0.5$ ) lambda ( $\Lambda$ ) and antilambda ( $\bar{\Lambda}$ ) production in Au + Au

collisions at  $\sqrt{s_{NN}} = 130$  GeV. The data were taken with the STAR (Solenoidal Tracker At RHIC) detector. The main components of the detector system for this analysis have been described in detail elsewhere [20]. They included a large volume time-projection chamber (TPC) [21], a pair of zero-degree calorimeters located at  $\pm 18$  meters from the center of the TPC, and a central trigger barrel constructed of scintillator paddles surrounding the TPC.

Data from both the minimum-bias trigger and the central trigger have been used for this analysis. Similar to a previous analysis [4], the collision centrality was defined offline using the total charged particle multiplicity within a pseudorapidity window of  $|\eta| < 0.5$ . The charged particle multiplicity distribution was divided into five centrality bins, corresponding to approximately the most central 5%, 5%–10%, 10%–20%, 20%–35%, and 35%–75% of the total hadronic inelastic cross section of Au + Au collisions.

The  $\Lambda$  and  $\bar{\Lambda}$  particles were reconstructed from their weak decay topology,  $\Lambda \rightarrow p\pi^-$  and  $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ , using charged tracks measured in the TPC [22]. Particle assignments for  $p$  ( $\bar{p}$ ) and  $\pi^-$  ( $\pi^+$ ) candidates were based on charge sign and the mean energy loss,  $\langle dE/dx \rangle$ , measured for each track. Candidate tracks were then paired to form neutral decay vertices, which were required to be at least 5 cm in distance from the primary vertex. The reconstructed momentum vector at the decay vertex was required to point back by a straight line to the primary vertex within 0.5 cm.

Figure 1 shows the invariant mass distributions for the reconstructed  $\Lambda$  and  $\bar{\Lambda}$  candidates in  $|\eta| < 0.5$  for two typical  $p_T$  bins from the data sample. The mass resolutions ( $\sigma$ ) for reconstructed  $\Lambda$  and  $\bar{\Lambda}$  are typically about 3–4 MeV/ $c^2$  based on a Gaussian fit to the peak. The background beneath the  $\Lambda(\bar{\Lambda})$  peak is dominated by combinatoric pairs of charged particles. Decays of  $K_S^0 \rightarrow \pi^+\pi^-$  also contribute to the smooth background due to pions misidentified as protons. The yield is obtained from the invariant mass distribution in each transverse momentum ( $p_T$ ) and rapidity ( $y$ ) bin, where the shape of the background near the  $\Lambda(\bar{\Lambda})$  peak is fit with a second order polynomial function. Variations in the yield due to different fits for the background have been included in the estimate of systematic errors. The raw yield for each  $p_T - y$  bin was then corrected for finite detection efficiency, which was calculated from embedding simulated  $\Lambda$  and  $\bar{\Lambda}$  particles in real collision events. Hadronic scatterings and antiparticle annihilations are included in the simulation. The combined acceptance and efficiency for  $\Lambda$  and  $\bar{\Lambda}$  ranges from 0.8% to 5.8% as a function of  $p_T$  for the most central collision sample.

The measured  $\Lambda$  spectra contain contributions from primordial  $\Lambda$ ,  $\Sigma^0$  decays, and feed-down from multiply strange hyperons—notably  $\Xi^0$  and  $\Xi^-$ . The primordial  $\Lambda$  and the  $\Sigma^0$  decay products cannot be separated in our

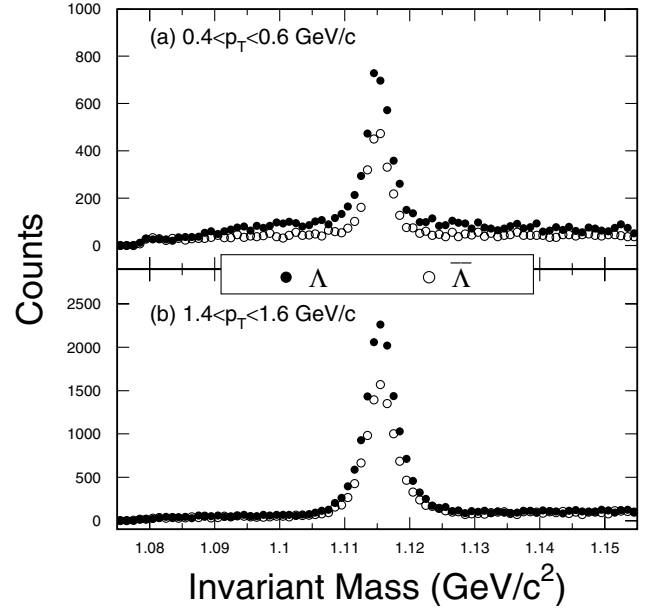


FIG. 1. Invariant mass distribution of  $\Lambda$  (solid circles) and  $\bar{\Lambda}$  (open circles) candidates from the data sample analyzed including both central and minimum-bias collisions: (a)  $0.4 < p_T < 0.6$  GeV/ $c$ ; (b)  $1.4 < p_T < 1.6$  GeV/ $c$ .

analysis and have been treated as primary  $\Lambda$ . We estimate the contributions of feed-down from multiply strange hyperons, mostly  $\Xi$  and  $\bar{\Xi}$  decays, to be approximately  $(27 \pm 6)\%$  of the measured  $\Lambda$  and  $\bar{\Lambda}$  yields, respectively. The estimate was based on the fact that the distance of the closest approach distribution of  $\Lambda$  from  $\Xi$  decays is different from that of primary  $\Lambda$  production, which we quantified by extensive comparisons between simulations and real data [22]. The spectra presented in this Letter include the decay contribution.

Figure 2 presents the  $m_T$  spectra (invariant distributions) of  $\Lambda$  and  $\bar{\Lambda}$  for five selected centrality bins. Combined systematic errors from various methods of yield extraction, reconstruction efficiencies, and uncorrected sector by sector variations in the TPC performance are estimated to be 10%. Both exponential ( $e^{-(m_T-m)/T_E}$ ) and Boltzmann ( $m_T e^{-(m_T-m)/T_B}$ ) functions have been used to fit the data. The slope parameter obtained from the exponential fit is systematically higher than that for the Boltzmann by approximately 40–65 MeV. However, overall the integrated yields from both fit functions are consistent within the statistical errors. The slope parameters and the  $dN/dy$  from these fits are presented in Table I. The Boltzmann form was adopted in Fig. 2 because it typically provides a better  $\chi^2$  and gives a reasonable description of the  $m_T$  spectra over the entire range of centrality and transverse momenta investigated.

Within the systematic error, the slope parameters measured for the  $\Lambda$  and  $\bar{\Lambda}$   $m_T$  distributions are the same. There is a systematic increase in the slope parameters from approximately 254 MeV for the least central (35%–75%)

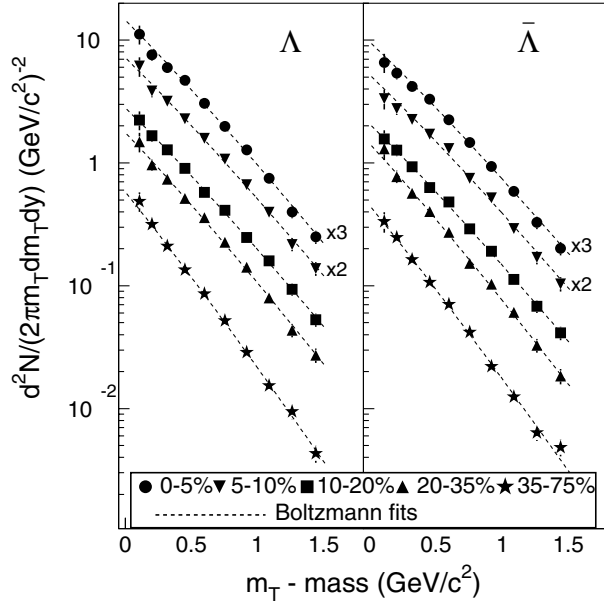


FIG. 2. Transverse mass distributions of  $\Lambda$  (left) and  $\bar{\Lambda}$  (right) at midrapidity ( $|y| < 0.5$ ) for selected centrality bins. The dashed lines are Boltzmann fits. Note that multiplicative factors have been applied to data from the two most central data sets for display.

to 312 MeV for the most central (0%–5%) bin. Similar behavior as a function of centrality is found for the  $\bar{p}$  transverse mass distributions [23]. Assuming the temperature at which particle interactions cease (the “freeze-out temperature” [24]) is constant independent of collision centrality, the increase in the slope parameter may be interpreted as an increase in the collective radial velocity [25,26].

A possible indication of hydrodynamic flow is the increase of the observed mean transverse momenta for various species with increasing particle mass. The transverse momentum distributions of negatively charged hadrons, as well as  $\bar{p}$  and  $\bar{\Lambda}$ , are shown in Fig. 3. The  $\bar{p}$  and  $\bar{\Lambda}$   $p_T$  distributions are similar in shape in the region where they can be compared (below 1 GeV/c), even though the data

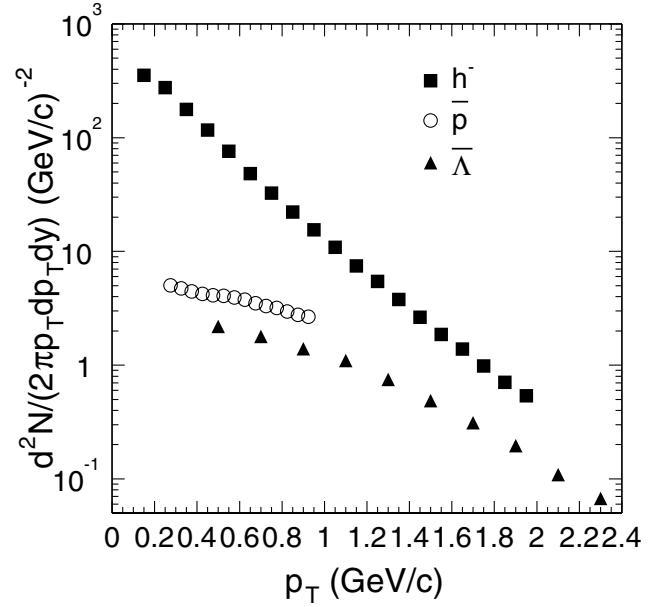


FIG. 3. The midrapidity  $\bar{\Lambda}$  ( $|y| < 0.5$ ) transverse momentum distribution from the top 5% most central collisions. For comparison the distributions for negative hadrons [ $d^2N/(2\pi p_T dp_T d\eta, |\eta| < 0.1$ )] and antiprotons ( $|y| < 0.1$ ) for the similar centrality bin are included. Statistical errors are less than the size of the data points.

sets cover somewhat different ranges in  $p_T$ . Both distributions are qualitatively different from and much less steep than the corresponding  $h^-$  distribution, which is dominated by pions. Qualitatively similar behavior was observed in heavy ion collisions at the CERN Super Proton Synchrotron (SPS) [25–27]. As predicted, the slope parameters for all species are observed to be larger at RHIC [28]. The increase was also described by thermal model fits, e.g., [29].

Figure 3 indicates that at higher  $p_T$  ( $p_T > 1$  GeV/c) the ratio of  $\bar{\Lambda}$  to negative hadrons increases rapidly. The baryon to meson ratio at RHIC for  $p_T > 1$  GeV/c exceeds expectations from perturbative QCD inspired string fragmentation models which were tuned to fit  $e^+e^-$  collision

TABLE I. Fit parameters from Boltzmann and exponential fits of the  $m_T$  spectra for  $\Lambda$  and  $\bar{\Lambda}$  at midrapidity ( $|y| < 0.5$ ). Only statistical errors are presented. The systematic errors on  $dN/dy$  and  $T$  are estimated to be 10%.

Centrality		0%–5%	5%–10%	10%–20%	20%–35%	35%–75%
$dN/dy$	$\Lambda$	$17.0 \pm 0.4$	$13.0 \pm 0.3$	$10.1 \pm 0.2$	$5.9 \pm 0.2$	$1.61 \pm 0.05$
(Boltz)	$\bar{\Lambda}$		$9.6 \pm 0.3$	$7.4 \pm 0.2$	$4.6 \pm 0.1$	$1.26 \pm 0.04$
$T_B$	$\Lambda$	$298 \pm 5$	$304 \pm 6$	$303 \pm 6$	$289 \pm 6$	$254 \pm 5$
(MeV)	$\bar{\Lambda}$	$312 \pm 6$	$310 \pm 6$	$305 \pm 6$	$280 \pm 6$	$258 \pm 5$
$dN/dy$	$\Lambda$	$17.4 \pm 0.4$	$13.3 \pm 0.3$	$10.4 \pm 0.2$	$6.1 \pm 0.2$	$1.66 \pm 0.05$
(exp fit)	$\bar{\Lambda}$	$12.3 \pm 0.3$	$9.8 \pm 0.3$	$7.6 \pm 0.2$	$4.7 \pm 0.1$	$1.30 \pm 0.04$
$T_E$	$\Lambda$	$355 \pm 8$	$364 \pm 9$	$362 \pm 8$	$343 \pm 8$	$295 \pm 7$
(MeV)	$\bar{\Lambda}$	$374 \pm 9$	$373 \pm 8$	$366 \pm 8$	$331 \pm 8$	$301 \pm 7$

data and are the basis for modeling particle production in hadronic collisions as well [5,30,31]. For example, the  $\bar{\Lambda}$  to  $h^-$  ratio is approximately 0.35 at  $p_T$  of 2 GeV/c. Data from  $e^+e^-$  collisions and calculations from string fragmentation models, however, indicate that, although the baryon to meson ratio from quark and gluon fragmentation increases as a function of Feynman  $x$ , the ratio never exceeds 0.2 [32]. As mentioned above, a natural explanation for the increase at high  $p_T$  would be a large collective radial flow at RHIC [24,27]. Alternatively, it has also been suggested that the energy loss of high  $p_T$  partons could modify the baryon to meson ratio [30].

The average ratio of  $p_T$  integrated yield  $\bar{\Lambda}$  to  $\Lambda$  is  $0.74 \pm 0.04(\text{stat}) \pm 0.03(\text{syst})$  with no significant variation over the measured range of centrality. Given that there is a net excess of baryons at midrapidity, it is reasonable to conclude that there is more than one process contributing to  $\Lambda$  production and that significant baryon number from the colliding beams is transported to  $\Lambda$  hyperons at midrapidity. A question in that regard is why the shapes of  $m_T$  spectra for  $\Lambda$  and  $\bar{\Lambda}$  are the same within errors. It has been suggested that significant rescattering of  $\Lambda$  and  $\bar{\Lambda}$  during the evolution of the collision can lead to equilibration [16,33]. Our measurement provides important constraints for modeling the mechanism of baryon number transport, which itself requires further study.

Figure 4 shows the  $dN/dy$  of  $\Lambda$  and  $\bar{\Lambda}$  from the Boltzmann fit as a function of the  $h^-$  pseudorapidity density [4]. At midrapidity the hyperon production is approximately proportional to the primary  $h^-$  multiplicity in Au + Au collisions at RHIC. The dashed lines in the figure correspond to  $\Lambda = 0.054h^-$  and  $\bar{\Lambda} = 0.040h^-$  from a linear fit to the data. The systematic errors on the hyperon yields and the  $h^-$  are 10% and 6%, respectively. Similar centrality dependence of the lambda production was observed at the SPS energies. The  $\bar{\Lambda}$  to  $h^-$  ratio at RHIC is much larger than that at the SPS while the  $\Lambda$  to  $h^-$  ratio is smaller at RHIC [13]. This may be understood from the fact that at the SPS most of the observed  $\Lambda$  hyperons carry baryon number transported from the colliding nuclei through associated production, rescattering, and fragmentation processes. In this case, the yield of  $\Lambda$  to  $h^-$  ratio is larger than that at RHIC due to the relatively high fraction of the  $\Lambda$  yield not resulting from pair production. Conversely, the increased importance of baryon pair production at RHIC energies must contribute to the observed increase of the  $\bar{\Lambda}$  to  $h^-$  ratio relative to the SPS measurement.

In conclusion, we have presented the first inclusive midrapidity ( $|y| < 0.5$ )  $\Lambda$  and  $\bar{\Lambda}$  spectra as a function of centrality from Au + Au collisions at the  $\sqrt{s_{NN}} = 130$  GeV energy. Salient features of the data include (i) large slope parameters of transverse mass spectra probably resulting from increased collective radial velocity at RHIC, (ii) similar shapes for  $\Lambda$  and  $\bar{\Lambda}$  spectra despite the fact that a significant fraction of the  $\Lambda$  hyperons

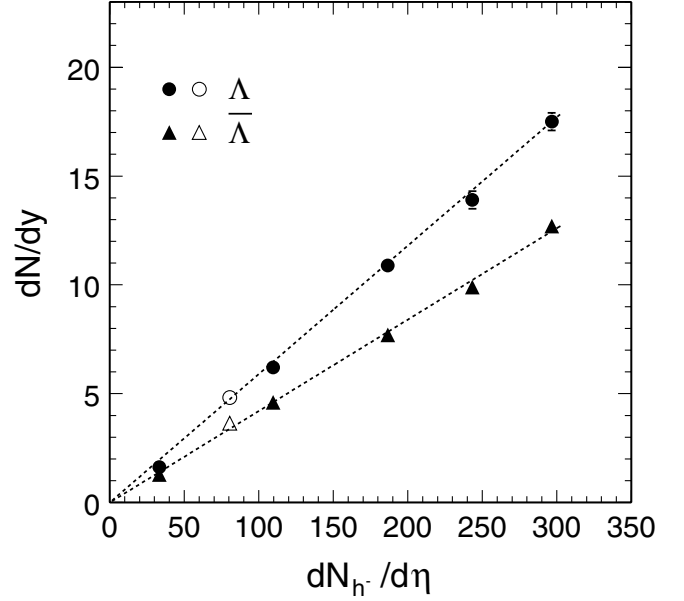


FIG. 4.  $\Lambda$  and  $\bar{\Lambda}$  rapidity density as a function of negative hadron multiplicity at midrapidity. The open symbols in the figure are data points from an independent analysis of minimum-bias data set using event-mixing techniques. Errors shown are statistical only.

at midrapidity carry a baryon number from the incoming nuclei while the  $\bar{\Lambda}$  hyperons are primarily pair produced, and (iii) a significant increase in the  $\bar{\Lambda}$  yield relative to negatively charged primary hadrons at moderate  $p_T$  above 1 GeV/c which cannot be described by existing perturbative QCD inspired string fragmentation models alone. Collective dynamics and/or modified string particle production schemes are needed. The  $p_T$  integrated rapidity densities of  $\Lambda$  and  $\bar{\Lambda}$  are approximately proportional to the number of negative hadrons at midrapidity.

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- [1] J.P. Blaizot, Nucl. Phys. **A661**, 3c (1999), and references therein.
  - [2] B.B. Back *et al.*, Phys. Rev. Lett. **85**, 3100 (2000).

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- [3] K. Adcox *et al.*, Phys. Rev. Lett. **86**, 3500 (2001).  
[4] C. Adler *et al.*, Phys. Rev. Lett. **87**, 112303 (2001).  
[5] B. Andersson *et al.*, Phys. Scr. **32**, 574 (1985).  
[6] J.R. Ellis *et al.*, Phys. Lett. B **233**, 223 (1989).  
[7] W. Busza and R. Ledoux, Annu. Rev. Nucl. Part. Sci. **38**, 119 (1988).  
[8] H.Z. Huang, in *Proceedings of the Relativistic Heavy Ion Symposium APS Centennial Meeting '99*, edited by R. Seto (World Scientific, Singapore, 1999), pp. 3–12.  
[9] D. Kharzeev, Phys. Lett. B **378**, 238 (1996).  
[10] J. Rafelski and B. Müller, Phys. Rev. Lett. **48**, 1066 (1982); **56**, 2334(E) (1986).  
[11] T. Abbott *et al.*, Phys. Rev. Lett. **64**, 847 (1990).  
[12] S. Ahmad *et al.*, Phys. Lett. B **382**, 35 (1996).  
[13] F. Antinori *et al.*, Eur. Phys. J. C **11**, 79 (1999).  
[14] H. Appelshäuser *et al.*, Phys. Lett. B **444**, 523 (1998).  
[15] P. Koch *et al.*, Phys. Rep. **142**, 167 (1986).  
[16] R. Bellwied *et al.*, Phys. Rev. C **62**, 054906 (2000).  
[17] H. Sorge, Phys. Rev. C **52**, 3291 (1995).  
[18] N. Amelin *et al.*, Phys. Lett. B **306**, 312 (1993).  
[19] R. Rapp and E. Shuryak, Phys. Rev. Lett. **86**, 2980 (2001).  
[20] K.H. Ackermann *et al.*, Phys. Rev. Lett. **86**, 402 (2001).  
[21] K.H. Ackermann *et al.*, Nucl. Phys. **A661**, 681c (1999).  
[22] H. Long, Ph.D. thesis, University of California, Los Angeles (2002); M.A.C. Lamont, Ph.D. thesis, University of Birmingham (2002).  
[23] C. Adler *et al.*, Phys. Rev. Lett. **87**, 262302 (2001).  
[24] E. Schnedermann, J. Sollfrank, and U. Heinz, Phys. Rev. C **48**, 2462 (1993).  
[25] I. Bearden *et al.*, Phys. Rev. Lett. **78**, 2080 (1997).  
[26] H. Appelshäuser *et al.*, Eur. Phys. J. C **2**, 661 (1998).  
[27] H. van Hecke *et al.*, Phys. Rev. Lett. **81**, 5764 (1998).  
[28] S. Bass and A. Dumitru, Phys. Rev. C **61**, 064909 (2000).  
[29] N. Xu and M. Kaneta, Nucl. Phys. **A698**, 306c (2002).  
[30] I. Vitev and M. Gyulassy, nucl-th/0104066.  
[31] X.N. Wang, Phys. Rep. **280**, 287 (1997).  
[32] W. Hofmann, Annu. Rev. Nucl. Part. Sci. **38**, 279 (1988).  
[33] P. Braun-Munzinger *et al.*, Phys. Lett. B **518**, 41 (2001).